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THE INTRODUCTION OF MIXED-POLARIZATION FOR V.H.F. SOUND BROADCASTING: the Wrotham installation

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Summary

The considerations that led to the decision to change the polarization of the v.h.f/f.m radio network transmitters from horizontal to mixed are discussed. The installation at Wrotham, the first high-power station to be changed to the new standard, is described and its performance given.

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1. Introduction

In July 1954 the Government authorized the introduction of a v.h.f. broadcasting service using frequency modulation within the frequency band 88 - 95 MHz and transmissions started on a regular basis in May 1955. The parameters for the new service had been intensively studied for some ten years prior to its introduction. Of particular interest are a number of low-power field trials carried out in 1945 and 1946 [1], which considered, among other things, the choice of polarization for the new service. At that time the v.h.f./f.m. service was thought of in terms of receiving antennas installed at roof level but was nevertheless considered to be limited by the prevailing high level of motor car ignition interference. Observations were made of the incidence of such interference with both vertically-polarized and horizontally-polarized transmissions[2]. It was noted that the interference with vertical polarization was between 6 dB and 10 dB higher in level than with horizontal polarization for the same field strength. The propagation characteristics of the two polarizations were also studied; vertical polarization gave marginally higher fields in the shadow of a hill and suffered less multipath from aircraft, otherwise there was little to choose between them[3]. As a basic receiving antenna a horizontal dipole was thought easier than a vertical dipole to install in the home (e.g. in a loft) and had the advantage that it conferred some directivity in the horizontal plane that was useful for reducing multipath as well as interference. (The use of v.h.f. receivers in cars was not considered a practicality at that time). But the overriding consideration was that of ignition interference and so the choice of horizontal polarization was made. Nevertheless it was remarked at the time that "while horizontal polarization is a superior to vertical from the point of view of motor-car interference, there might be a case for preferring vertical polarization if suppressors were universally fitted to motor vehicles" [1].

In the intervening years there has indeed been a drop in the general level of ignition interference. Legislation to make suppressors compulsory for new vehicles came into force a a number of years ago and it is now rare to encounter an unsuppressed vehicle. At the same time other changes have taken place. The a.m. suppression ratio of receivers has improved. The service has moved from monophony to stereophony and two new classes of listener have emerged that were not considered in the original planning, those with portable receivers and those riding in motor vehicles. It is the appearance of this new audience that has precipitated a reconsideration of the polarization to be used.

It may be shown theoretically that the field strength of a vertically-polarized (v.p.) transmission is higher close to the ground than that of a horizontally-polarized (h.p.) one. Also, listeners commonly use the whip antenna on a portable receiver in a vertical, or near vertical, position since it is then easier to handle. Similarly cars are normally fitted with a vertical whip antenna and rely on coupling with currents induced on the bodywork to give a response to a horizontally-polarized transmission. Field measurements confirmed that these classes of listener would obtain substantial benefits from the radiation of a vertically-polarized component[4]. On the other hand a substantial number of listeners employ fixed horizontally-polarized receiving antennas. Accordingly the decision was taken to maintain the horizontally-polarized transmission at about the same power level and to add a vertically-polarized component also at this power level.

A number of low-power stations, particularly those built more recently for local radio, are already in service with mixed polarization. A programme of refurbishing the high-power stations carrying national network programmes has now been started and Wrotham, serving London and south-east England, is the first rebuilt station to be brought into service.

2. International implications

The v.h.f. band reserved for broadcasting in Region 1 (which includes the United Kingdom) at the Atlantic City Conference held in 1947 was 87.5 - 100 MHz. Frequency allocations within this band were made at the Stockholm Broadcasting Conferences in 1952 and 1961. Thus each of the three frequencies in use at Wrotham was allowed under the 1961 agreement an effective radiated power (e.r.p.) of 250 kW from a non-directional antenna having an effective height of 300m.* The polarization of these, and of all other allocations in the 1961 plan, was horizontal. The maximum

* Effective height is defined as the height of the antenna over the average level of ground between distances 3 and 15 km from the transmitter in the direction of the receiver.

power allowed at Wrotham was not taken up, (the maximum e.r.p. was 135 kW), nor was any implementation made of a fourth frequency allocation. It may also be noted that one neighbouring country, Eire, implemented their allocations with vertical rather than horizontal polarization.

It may be seen that, although the power in the horizontally-polarized component at Wrotham (and some other UK sites) could have been doubled without recourse to international negotiation, to add the extra power in the form of a vertically-polarized component was not so clearly justified and negotiation with neighbouring countries was needed. In order to assist this process it was decided to limit the maximum e.r.p. of each component to 125 kW; the total e.r.p. would not then exceed the Stockholm power.

Thus, various uncertainties exist which may not be resolved until the second session of the ITU planning conference scheduled for 1984. At this conference frequency allocations will be made in the extended band 88 - 108 MHz. Accordingly any new antennas for network broadcasting must be designed for this much greater bandwidth.

3. Types of polarization

So far reference has been made only to the horizontally- and vertically-polarized components of the radiated signal, with no consideration of the relative phase between them. It is appropriate here to consider the various terms in use to describe combinations of horizontally- and vertically-polarized components with different phase relations and the extent to which this phase relation may be controlled in a practical situation.

3.1. Slant polarization (s.p.)

This is linear polarization in which the electric vector is at some arbitrary angle to the vertical, in the plane normal to the direction of propagation, usually near to 45°. The polarization is said to be right-hand or left-hand slant when the electric vector has been rotated clockwise or anti-clockwise, respectively, by up to 90° from the vertical position, when looking in the direction of propagation. Thus slant polarization may be considered to result from the sum of horizontally- and vertically-polarized components that are in phase.

3.2. Elliptical polarization (e.p.)

At a fixed point the field variation with time is such that the tip of the electric vector describes an ellipse in the plane normal to the direction of propagation. It may be regarded as being the sum of a horizontally- and a vertically polarized component which may have any finite amplitude ratio and any phase difference.

Circular polarization (c.p.) is a special case of elliptical polarization for which the amplitudes of the horizontal and vertical components are equal and in phase quadrature. At a fixed point the field varies with time so that the tip of the electric vector describes a circle in one of two possible senses. If, when the observer looks in the direction of propagation, the direction of rotation is clockwise, the polarization is described as right-hand circular. When the direction of rotation is anti-clockwise the polarization is described as left-hand circular.

3.3. Mixed polarization (m.p.)

This is a general term describing elliptical or slant polarization, often with horizontal and vertical components of equal amplitude but with an undefined phase difference.

3.4. Practical considerations

Transmitting antennas may be regarded in general as radiating both horizontally-polarized and vertically-polarized components. A well designed antenna for horizontal polarization will radiate a v.p. component of relative level −25 dB or less. A circularly-polarized antenna should, strickly speaking, have equal h.p. and v.p. components in phase quadrature in all directions of azimuth and elevation. In practice the polarization is elliptical in most directions. The h.p. and v.p. components will have different variations with azimuth and elevation and the phase difference between them will not be constant. The extent of the variations will depend on the form of the antenna; typical values for a wide-band high-power antenna are +2 dB in relative amplitude and ± 30° in phase.

Thus an antenna that gives circular polarization in one direction of azimuth may give markedly elliptical polarization in another. For this reason it is better to use the more general term "mixed polarization" unless dealing with either very simple antennas or special antenna arrays having well- controlled polarization.

4. The Original Horizontally-Polarized antenna at Wrotham

The original antenna[5] comprised eight tiers each of four vertical slots symmetrically disposed around a 2m diameter metallic cylinder. The antenna was designed for the frequency band 88 - 95 MHz and could not have been readjusted to yield a much greater bandwidth. Within its design bandwidth however its performance was very good. In particular, the horizontal radiation pattern was very uniform, with a maximum/minimum ratio of less than 1 dB (See Figure 1).

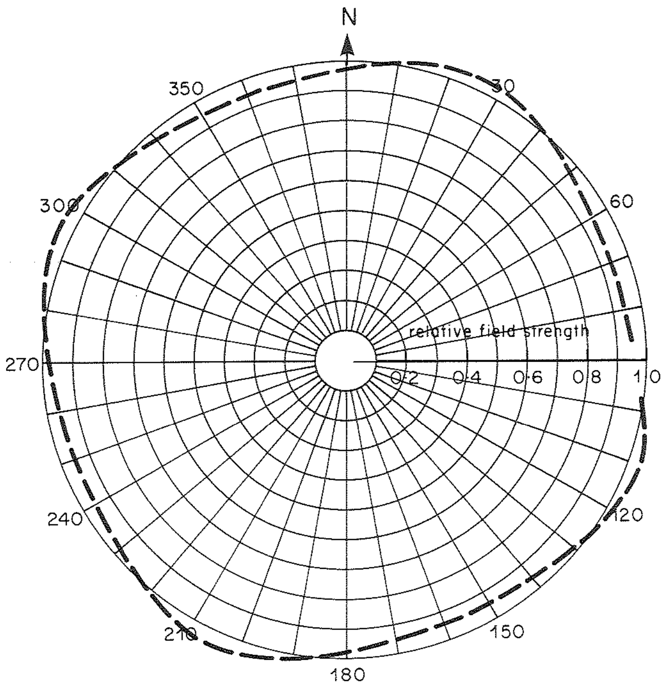

Fig. 1 - H.r.p. of existing horizontally-polarized antenna.

panels suitable for mounting around a support mast.

It was known that two UK manufacturers were each developing antenna designs for the application but the likelihood of a satisfactory outcome was not known. Accordingly some limited development was started in BBC Research Department. The objective was twofold: to provide guidance on the choice of specification limits and to provide a 'fall-back' position in case the commercial ventures failed.

The preferred arrangement was for panels

5. Preliminary investigations

As there was not suitable UK design of antenna, a survey was made of designs available elsewhere, principally in the United States of America where the use of mixed polarization had been growing for some years, partly because under FCC rules it has permitted operators to double their operating power. The majority of mixed-polarization antennas on the U.S. market were for single channel operation (bandwidth 200 kHz). One design had a bandwidth of 5 MHz but even this could not have been used in the UK situation for mechanical reasons.* It was apparent therefore that a new wide-band antenna would need to be developed and that this should take the form of

* Subsequently at least one design of wide-band mixed-polarization panel-mounted antenna has appeared on the American market.

mounted on a triangular cross-section mast, since this would have the lowest cost. Accordingly each panel was required to cover a sector of ± 60° in azimuth with a relative field amplitude of about 0.5 at these limits. The bandwidth requirement was quite large (1.25:1) and so consideration was given to a radiating element with an inherent wide-band capability - the batwing. The arrangement investigated was one of alternate horizontally- and vertically-polarized batwing elements on each face of a triangular structure. One tier of the arrangement was constructed and the horizontal radiation patterns measured with a range of spacings between element and reflector. The best patterns measured had a maximum/minimum value on one component of about 5 dB, which was somewhat disappointing. Such an arrangement would also give a less-than-ideal vertical radiation pattern owing to the wide

vertical spacing between corresponding elements.

Another but more expensive arrangement is to have panels mounted on a structure of square cross-section. For this configuration each panel should ideally have a horizontal radiation pattern falling to half amplitude at ± 45°. A new type of radiating element giving slant polarization was developed as shown in Figure 2. A 1.5 wavelength dipole is cranked to give approximately equal levels of radiation in horizontal and vertical polarizations. A one-fifth scale model of one tier of the arrangement was constructed and the horizontal radiation patterns were measured. The maximum/minimum ratios in decibels at the corresponding full scale frequencies after averaging were as follows:-

f, MHz :	88	92	96	104	108
h.p. component :	5.3	3.4	2.0	2.0	1.6
v.p. component :	2.0	1.1	0.5	1.3	2.3

The panel width at full scale was 2.4m.

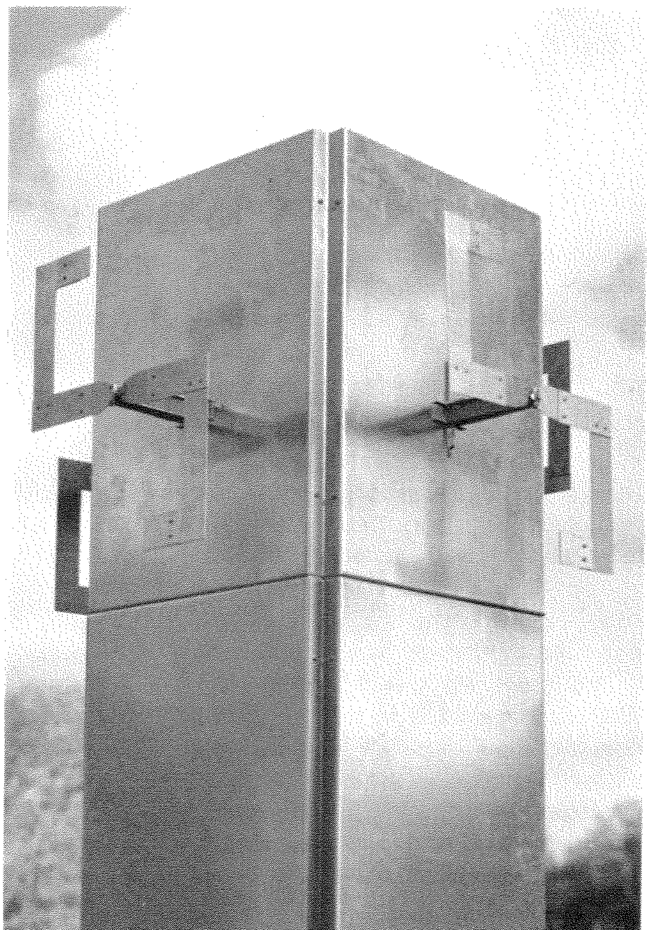

Fig. 2 - Model of slant-polarized elements on a square-section mast.

The arrangement was also matched to give a reflection coefficient not exceeding 0.1 over the frequency band. There is a drawback to the arrangement in that the balance between the horizontal and vertical components varied between +1.5 dB and −2.0 dB across the frequency band, so that these figures would have to be added to the maximum/minimum ratios when assessing the reduction of field from the existing condition.

Although this design looked fairly promising there were still some problems to be resolved and it appeared that an antenna based on it would be more costly and take longer to build than possible commercial designs. Accordingly development was stopped as soon as it became reasonably certain that there would be a viable commercial design.

6. Specification of mixed-polarization antenna

There were two aspects of the specifications that occasioned particular consideration, namely the radiation patterns and the impedance. The relevant factors will be outlined here.

6.1. Radiation patterns and gain

The objective was an antenna that did not radiate significantly less horizontally-polarized component in any direction than the original one and radiated an approximately equal vertically-polarized component. It was realised that this ideal could not be met completely and that some reductions in the horizontally-polarized component would have to be accepted. The most certain way of minimizing the loss was to write a specification that was tight but realistic. It appeared from computed h.r.p.s. and from the model measurements described in Section 5 that it might be possible to obtain a maximum/minimum ratio not exceeding 4 dB; the specification was therefore set at 3.5 dB. The two components could then deviate by this amount. However it was not known whether the maximum of the two components would co-incide and moreover, at this stage, the exact form of international restrictions had still to be determined. Accordingly for each programme the antenna was required to give maximum e.r.p.s of 125 kW in both polarizations with the available transmitter power and to provide mean e.r.p.s of at least 110 kW.

In the event the last requirement could not be met.

6.2. Impedance

The original antenna was set up to have a reflection coefficient to the main feeder not exceeding 0.05 but this was achieved only at great expense of which development work and adjustment accounted for an appreciable proportion. A later study[6] allowed some relaxation, arriving at a value of 0.08 for Wrotham. However this specification was for monophonic transmissions and made allowance for the use of receivers that had no limiter. It was therefore necessary to amend the specification to allow for stereophonic transmissions and for the general improvement in the performance of receivers that had occurred.

The new specification was arrived at by both theoretical studies and subjective tests and was supported by an independent study[7]. It required that the reflection coefficient of each half aerial should be such that the amplitude of any delayed signal radiated by the antenna, expressed as a percentage of the primary signal, should not exceed 15%. This was on the assumption that the delay would not exceed 5 μs, corresponding to the time for a reflected signal to traverse down and up the main feeder with some allowances for delay in the combining filters.

7. The new mixed-polarized antenna at Wrotham

7.1. Description

The Wrotham transmitting station is located 35 km south-east of the centre of London and its transmissions are designed to serve the whole of London and south-east England. It is the first high-power station in the United Kingdom to be converted to mixed-polarization.

A new support mast was built adjacent to the old one. The new mast is slightly taller than the old one so that the mean height of the new mixed-polarized antenna is 28.6m higher at 149.9m above ground level. Figure 3 shows the arrangement.

The antenna, which was designed and constructed by Alan Dick & Co. Ltd., comprises 10 tiers, each of three panels per tier of mixed-polarized radiating elements. The latter are crossed half-wave dipoles mounted on a reflecting screen, with the dipole limbs angled back towards the screen (see Figure 4). The dipoles are driven

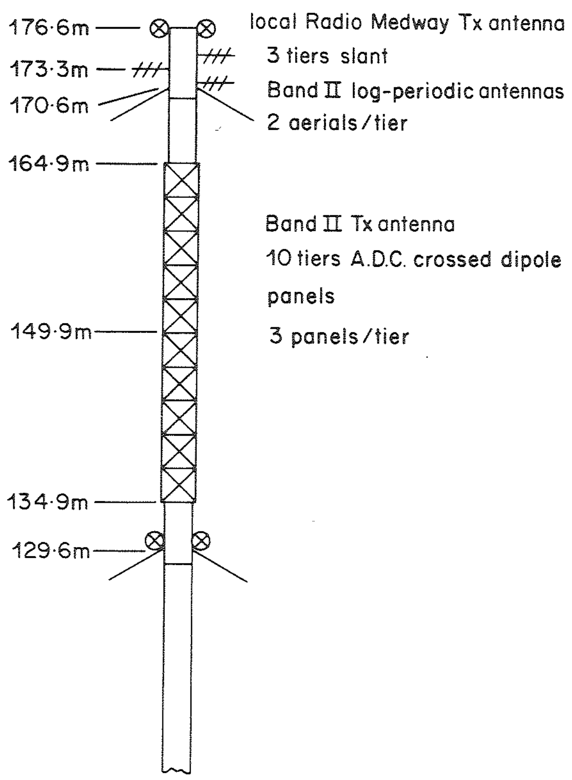

Fig. 3 - Outline of new mast at Wrotham.

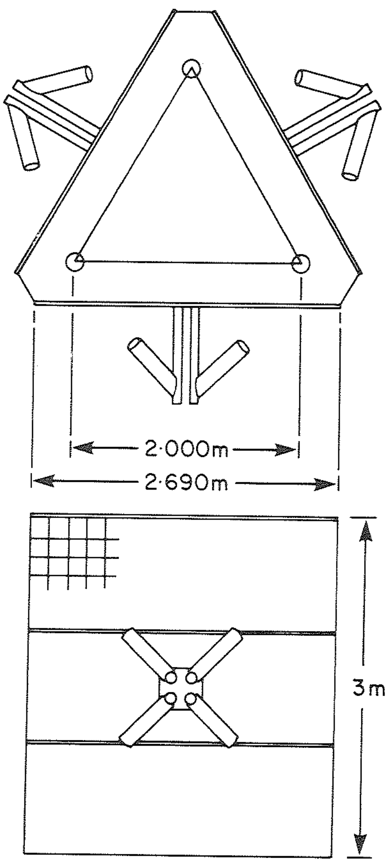

Fig. 4 - Mixed-polarized element panels.

in phase quadrature so that the polarization is circular in directions normal to the panels. Adjacent tiers are fed in phase quadrature and the dipoles rotated by 90° to maintain the radiation in the correct phase; this arrangement improves the reflection coefficient of the whole antenna.

It may also be noted that the powers radiated in the two polarizations in the horizontal plane are necessarily equal at all frequencies, notwithstanding any inequality between pairs of dipoles. Figure 5 shows a photograph of four tiers of the antenna taken during works tests.

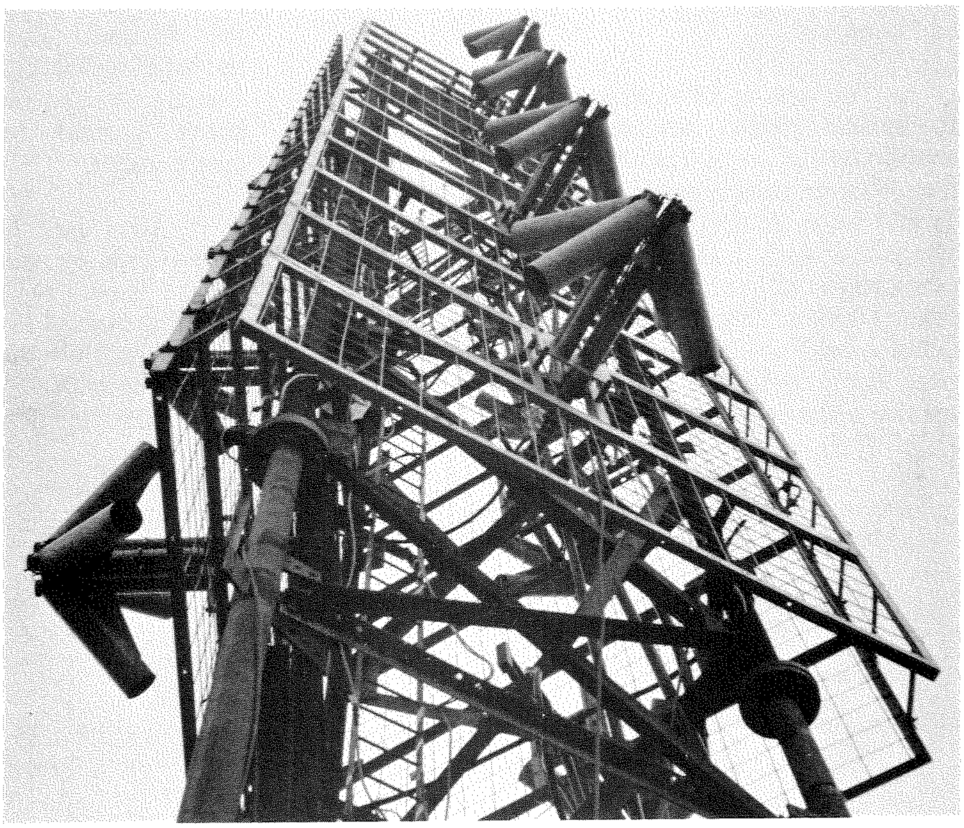

Fig. 5 - Four tiers of the Wrotham mixed-polarized antenna under test at works.

7.2. Radiation patterns

The horizontal radiation patterns of the mixed polarized antenna are shown in Figures 6 - 8 inclusive. The uniformity is generally fairly good. It is a little unfortunate, however, that the least uniform patterns for horizontal polarization occur at the lowest frequencies where the existing services are located rather than at higher frequencies where new services are planned.

The horizontal and vertical components are in phase quadrature in directions normal to the panels so that the polarization is circular in these directions. In other directions of azimuth the relative phase deviates from the quadrature condition by up to 45° (see Fig.9) so that in these directions the polarization is elliptical.

Figure 10, 11 and 12 show the vertical radiation patterns. Some phase perturbation of the extreme tiers has been applied in order to give a degree of gap-filling to the first null of the v.r.p. There is an increase of high-angle radiation at the highest frequency owing to the use of an inter-tier spacing that is slightly greater than one wavelength at this frequency.

7.3. Gain

The gain of the antenna was calculated from tabulated values[8] assuming that the individual tiers had a vertical radiation pattern of the form $E_\theta = (1 + P\cos^2\theta + Q\cos^4\theta)^{1/2}$ where θ is the angle to the vertical. The values P = −1, Q=0 were found to give the best fit to the measured patterns, i.e. they obey a sine law. Details of the gain/loss calculation for the existing network frequencies are given in the Appendix.

As this antenna gives inherently equal components in horizontal and vertical polarizations, the mean e.r.p. is determined by that component having the greater maximum/mean ratio of the h.r.p. if the value of 125 kW is not to be exceeded by either component.

Fig. 6

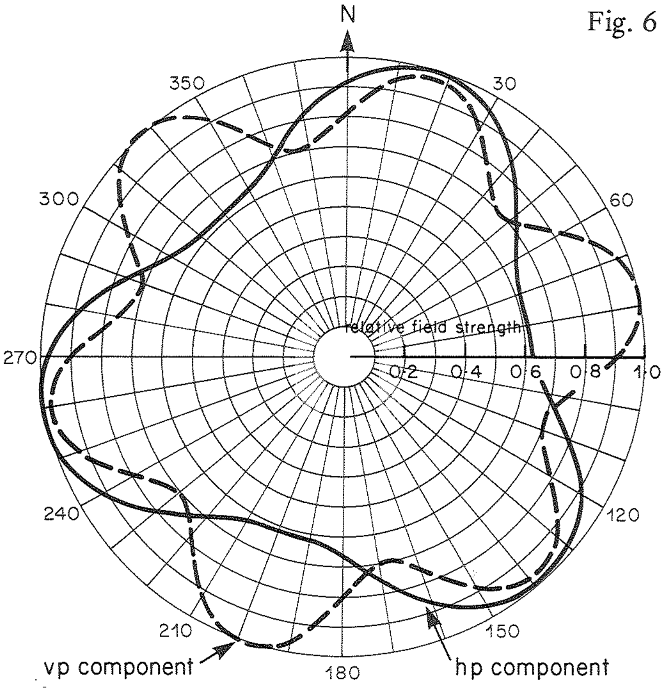

Fig. 7

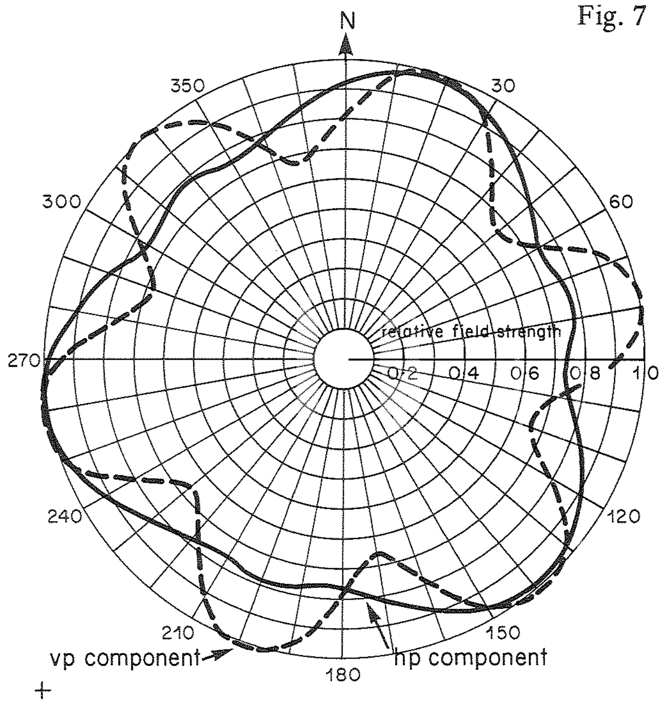

Fig. 8

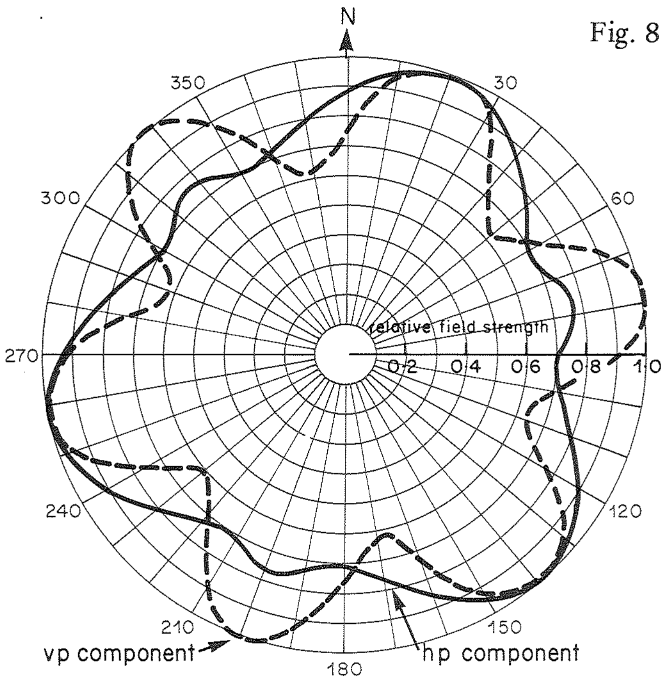

Fig. 6 - H.r.p.s of mixed-polarized antenna at 88 MHz.

Fig. 7 -H.r.p.s of mixed-polarized antenna at 96 MHz.

Fig. 8 - H.r.p.s of mixed-polarized antenna at 108 MHz.

7.4. Impedance

The reflection coefficient of the antenna does not exceed 10% at any frequency in the band for the half antennas fed together or for either half fed separately.

8. Conclusions

The horizontally-polarized antenna at Wrotham has been replaced after 31 years of service. The new antenna radiates with mixed polarization and is capable of radiating five high-power network programmes within the frequency band 88 - 108 MHz. The horizontal radiation patterns of the new antenna are slightly less uniform that those of the old one and for this reason and because the maximum permitted radiated power is lower, the effective radiated power of the horizontally-polarized component averaged over all horizontal directions is 1.3 dB lower. This reduction has been partially offset by a need to underrun the old installation in recent years. The mean height of the new antenna is however 28m higher.

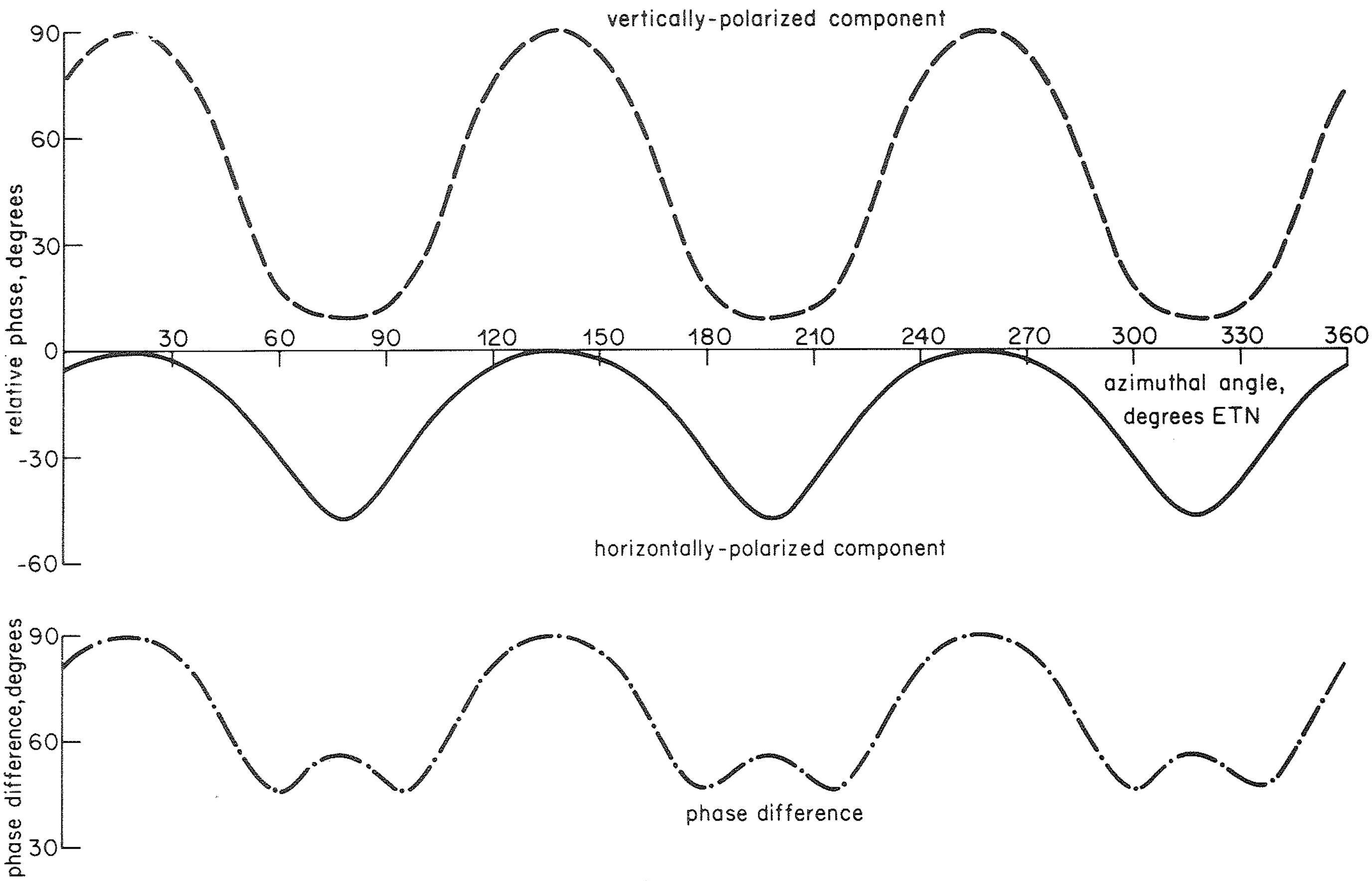

Fig. 9 - Relative phase of horizontally- and vertically-polarized components at 88 MHz.

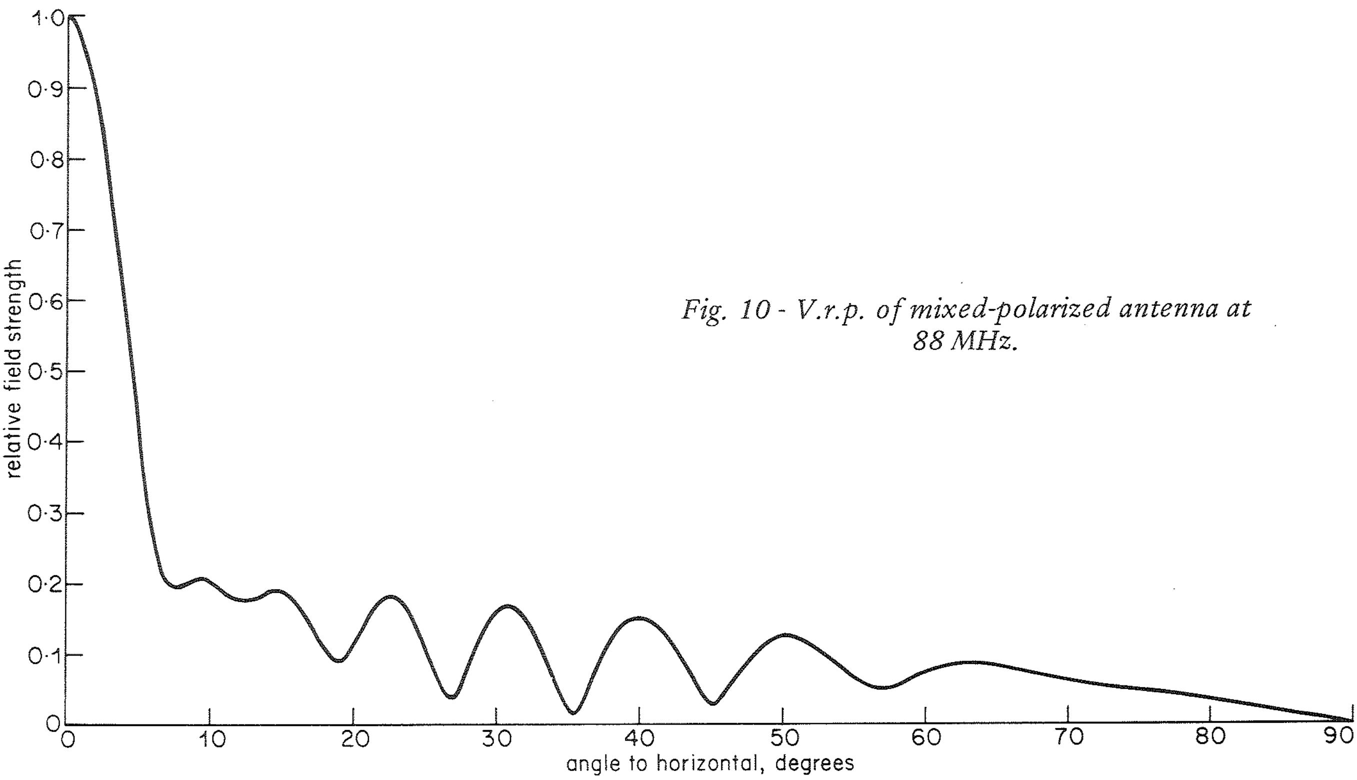

Fig. 10 - V.r.p. of mixed-polarized antenna at 88 MHz.

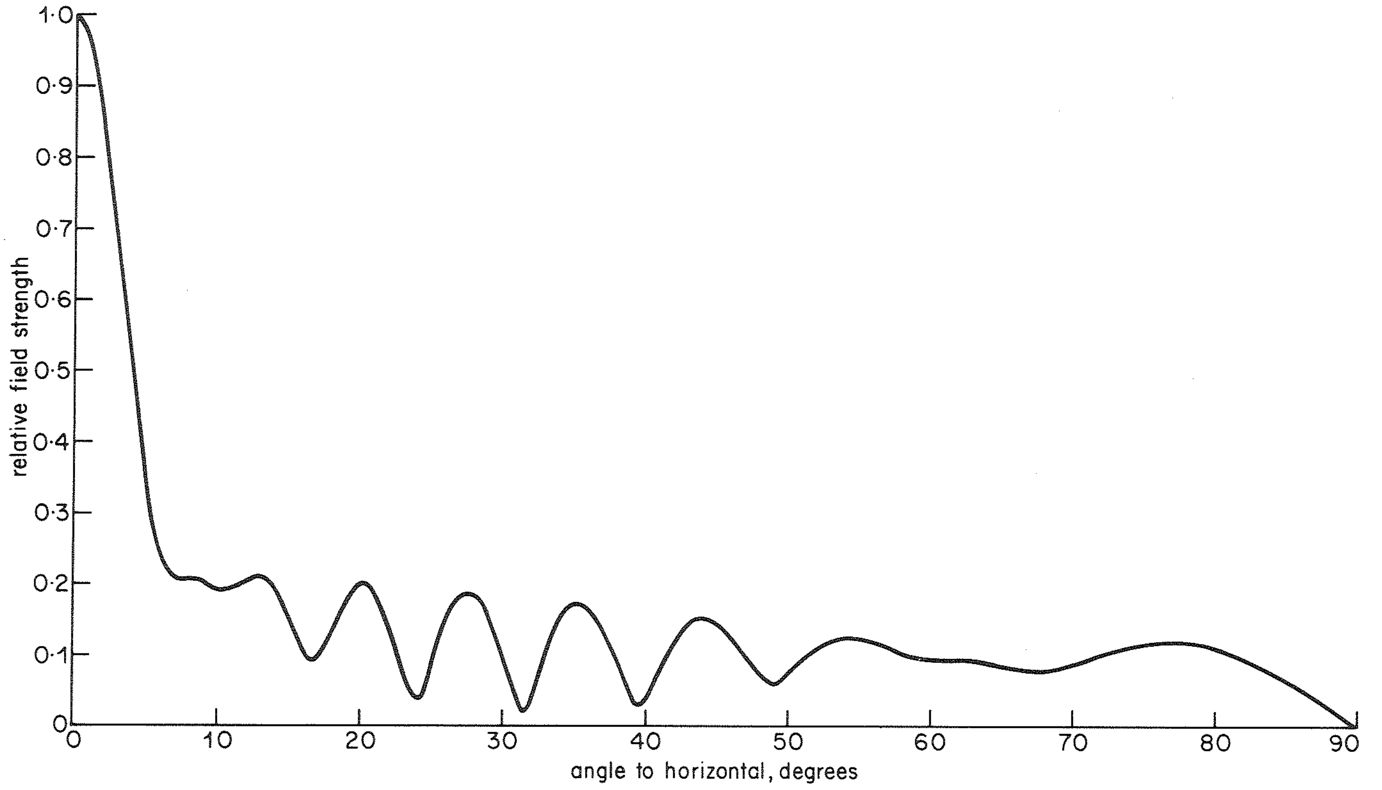

Fig. 11 - V.r.p. of mixed-polarized antenna at 98 MHz.

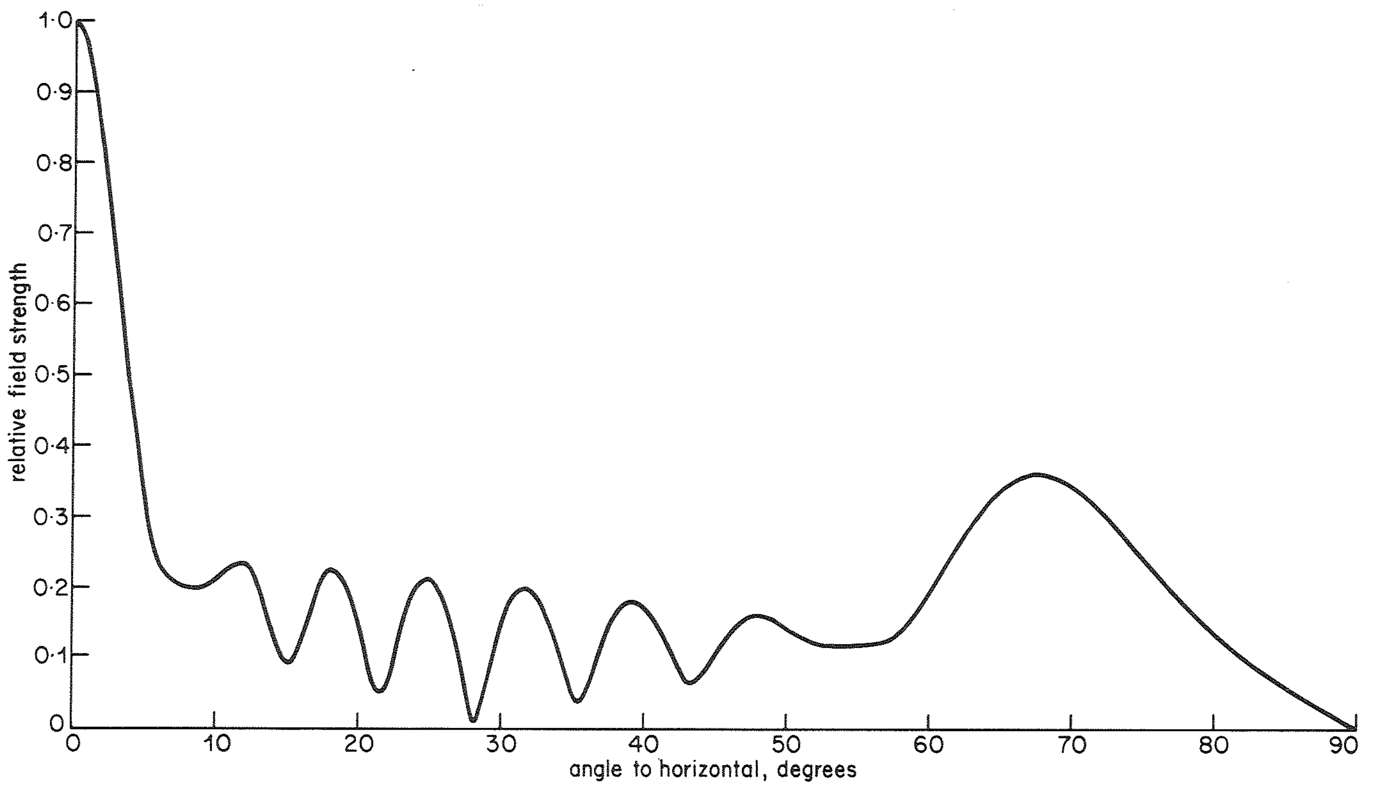

Fig. 12 - V.r.p. of mixed-polarized antenna at 108 MHz.

The overall performance of the transmitter must be judged in relation to the service area that it provides and this is the subject of a separate study. Preliminary indications are that the objectives have been met for car and portable radio reception whilst domestic reception on fixed horizontal antennas is not significantly affected.

9. References

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APPENDIX

The gain/loss calculation for the existing network frequencies is as follows:-

Frequency:	98.1 MHz	91.3 MHz	93.5 MHz
Network:	R 1/2	R 3	R 4
Aperture, λ	8.92	9.14	9.36
Gain factor	1.069	1.095	1.116
Mean intrinsic gain, dB	10.29	10.39	10.48
Distribution, misalignment, dB	0.4	0.4	0.4
Null fill loss dB	1.07	1.16	1.23
Polarization loss dB	3.0	3.0	3.0
Main feeder loss dB	0.5	0.5	0.5
Combiner loss dB	0.8	0.8	0.8
Mean effective gain, dB	4.52	4.53	4.56
Mean e.r.p., either component, kW	85.5	90.3	90.5
Required transmitter power kW	30.2	31.8	31.7
H.r.p. Max/mean H, dB	1.70	1.41	1.39
H.r.p. Max/mean V, dB	1.42	1.39	1.40
Max e.r.p. H, kW	125	125	125
Max e.r.p. V, kW	117	124	125

The calculation for frequencies in the upper part of the frequency band is as follows:-

Frequency	96 MHz	100 MHz	104 MHz	108 MHz
Aperture, λ	9.61	10.01	10.41	10.81
Gain factor	1.135	1.129	1.076	1.015
Mean intrinsic gain, dB	10.55	10.53	10.32	10.06
Distribution and misalignment, dB	0.4	0.4	0.4	0.4
Null fill loss, dB	1.29	1.35	1.38	1.39
Polarization loss, dB	3.0	3.0	3.0	3.0
Main Feeder loss, dB	0.5	0.5	0.5	0.5
Combiner loss, dB	0.8	0.8	0.8	0.8
Mean effective gain, dB	4.56	4.48	4.24	3.97
Mean e.r.p., either component, kW	89.4	89.1	88.8	86.9
Required transmitter power kW	31.3	31.8	33.4	34.8
H.r.p. max/mean H, dB	1.32	1.20	1.08	1.58
H.r.p. max/mean V, dB	1.46	1.47	1.48	1.58
Max e.r.p., H, kW	121	117	114	125
Max e.r.p., V, kW	125	125	125	125